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RESEARCH NOTE

STEREO-DEFICIENTS AND STEREOBLINDS CANNOT MAKE UTROCULAR DISCRIMINATIONS

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Abstract—In two separate experiments, we show that stereo-deficient observers are no better than stereonormals at discriminating the eye-of-origin of a monocular stimulation. Stereo-deficient observers are considered to have a preponderance of monocular neurons throughout their visual system, including the visual cortex. The results indicate that, in spite of their clear anatomical and physiological structure, such monocular neurons do not convey eye-of-origin information to consciousness.

Utrocular Eye-of-origin Stereo-deficient Stereoblind Amblyopia Monocular neurons Binocular vision Psychophysics

Utrocular discrimination refers to the ability to specify which of the two eyes receives a particular, *monocular* stimulation in the *absence* of extraneous cues. Relative to stereonormal individuals, who have a normal complement of cortical cells responsive to the stimulation of either eye (i.e. binocular cells), it has been argued (Blake and Cormack, 1979a) that stereo-deficient observers are particularly adept at making eye-of-origin or utrocular discriminations because of their presumed preponderance of cortical cells responsive to the stimulation of one eye only (i.e. monocular cells). Blake and Cormack (1979a) used a paradigm in which homogeneous, equiluminant fields were viewed in a mirror haploscope. With the two fields in binocular register, one was briefly changed to a vertical, sine-wave grating while the other remained unchanged. Different spatial frequencies were used, ranging from 0.5 to 8.0 c/deg, and the observers were asked to identify the eye flashed with the grating. They found that as spatial frequency increased the utrocular discriminations of the stereonormals fell to chance for frequencies ranging from 1 to 4 c/deg, depending on the individual. In contrast, the discriminations of the stereo-deficients remained unchanged over the range of frequencies tested: Blake and Cormack attributed this result to the preponderance of monocular cortical neurons in the stereo-deficients.

Because of its significance as a link between physiology and perception, we wish to report the results of two, *independent* investigations which show that the ability to identify which eye receives a monocular stimulation is *not* related to the absence or near-absence of stereopsis. Given that stereo-deficient persons have a preponderance of monocularly driven neurons in the cortex, and indeed probably a preponderance of monocular neurons throughout their visual system, this finding indicates that such monocular neurons do not convey their eye-of-origin information to consciousness. This lack of awareness of an eye-of-origin label in the visual system is surprising given the clear anatomical structure of ocular dominance columns. The fact that stereo-deficients are no more successful than stereonormals at making utrocular discrimination has broad implications: namely, that a physiological or anatomical, *cortical* substrate does not always imply a perceptual correlate.

At the outset it must be emphasized that, because of the abundance of potential differences between the percepts of the two eyes, it is easier than not to find observers who apparently can discriminate the eye-of-origin. Many such extraneous or nonvalaid cues have been discussed in the literature, and they include visual direction (Enoch *et al.*, 1969; Ono and Barbeito, 1985; Templeton and Green, 1968) and oculomotor adjustment (Smith, 1945). Further aggravating this difficulty is the fact that the extraneous cues may be more salient and prevalent among stereo-deficients (Levi, 1985). The sometimes complicated procedures used in the experiments described below were designed to obviate such cues.

In one of our studies, amblyopic, stereo-deficient observers viewed a homogeneous field ($0.5\ cd/m^2$) presented to each eye in a mirror haploscope in an otherwise dark room. A 100 msec flash of a high-contrast, low-spatial-frequency (1 c deg), sine-wave grating was presented to one eye, and the field visible to the other eye was either simultaneously changed in intensity or was left unchanged. The observer was always required to identify the eye stimulated by the grating and was not informed about the possibility of a luminance change. Note that for the condition in which the luminance was not changed, the paradigm is essentially identical to the used by Blake and Cormack (1979a).

When stereonormals were tested in this paradigm, the frequency of correct responses was found to vary systematically with the magnitude of intensity change—the greater the change in intensity the greater the frequency of incorrect responses, with chance results occurring at some intermediate magnitude(s) of intensity change (Fig. 1). Further, in the zero luminance change condition, normals often show above chance, correct responses (Blake and Cormack, 1979a,b; Ono and Barbeito, 1985). This finding has been attributed to the "feeling-in-the-eye" associated with the "local" luminance variations produced when the homogeneous field changes to a low spatial frequency grating, i.e. to wide bars of high and low luminance (Blake and Cormack, 1979b; Ono and Barbeito, 1985). Indeed, Ono and Barbeito (1985) have demonstrated that the luminance change produces the feeling upon which the observers' utrocular responses depended, and, they have argued that it is an extraneous cue that must be controlled in utrocular experiments*. The fact that chance results occur for intermediate luminance changes was presumed by them to indicate that the feeling produced by the grating equalled that produced by the luminance change of the homogeneous field in the other eye; with the feeling balanced in the two eyes,

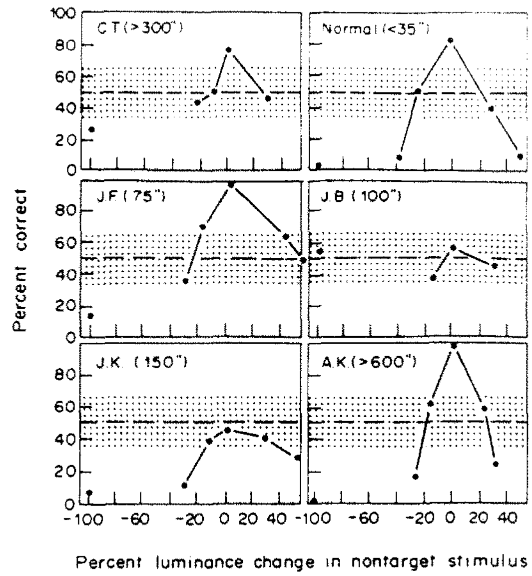

Fig. 1. Per cent correct identifications as a function of the luminance change presented to the eye not viewing the grating for five stereo-deficient and on stereonormal observer. Positive values on the abscissa represent luminance increases and negative values luminance decreases. Values in parenthesis are stereothresholds carefully determined by the Stereo Reindeer Test (Bernell Corporation). The stippling delimits the region of chance-level responses for $P < 0.05$ for the 50 trials represented by each point. (This region is *underestimated* since we did not correct for the increase in the probability of Type I error associated with making multiple tests of the null hypothesis.) The visual characteristics of the observers were: C.T., anisometropic amblyope, 20/20 and 20/200; J.F., small angle hypertropic amblyope, 20/12 and 20/24; J.K. and J.B., accommodative esotropes, 20/12 and 20/26 and 20/15 and 20/25 respectively; A.K., surgically corrected esotrope, 20/20 and 20/25.

utrocular discriminations fall to chance. (For more complete details of this methodology and of the results of stereonormal observers, see Ono and Barbeito, 1985.)

Of the five stereo-deficients we tested in this paradigm (stereothresholds ranged from 75" to >600"), three showed the general pattern found for stereonormals. The discriminations of the fourth was usually at chance, while that of the fifth never rose above chance levels (Fig. 1). Of particular interest is the zero luminance change condition, the one used by Blake and Cormack (1979a). In this condition, the utrocular discriminations of two of the five stereo-deficients was at chance, and that a third barely made statistical significance even with our liberal cut-off criterion which favors finding greater-than-chance discriminations. Like the normals, statistically significant discriminations, whether correct or incorrect, were associated with observer's reports of using the feeling cue. And, chance results were associated with failing to detect the feeling. The observation that stereo-deficient and stereonormal observers responded in essentially the same manner in this task indicates that the utrocular responses of both types of

*What constitutes "true" utrocular discrimination is the subject of some disagreement (for a discussion, see Steinbach *et al.*). In fact, we disagree among ourselves as to whether the "feeling" should be considered an extraneous cue. Ono and Barbeito (1985) argued that the utrocular question is whether the visual impressions of one eye can be distinguished from those of the other. Thus, in the paradigms we describe, the observer who can make utrocular discriminations should be able to identify the eye stimulated by the grating, since that is what s/he is asked to do. The other authors require only that the cue originate in some visual pathway. Thus, for example, the cue might originate as a luminance flash and be sensed as a feeling-in-the-eye as a result of innervation to the ciliary muscles of the pupil. In fact, when the two patterns are carefully matched, removing all visual cues, the feeling cue should be the only utrocular cue remaining. Thus, whether utrocular discrimination is indeed possible, by both stereonormals and stereo-deficients, depends on the definition of the question, that is, whether the feeling is considered an extraneous or a legitimate cue. We would like to stress, however, that this controversy is not germane to the issue dealt with in this paper, i.e. whether stereo-deficients have an advantage over stereonormals when doing a utrocular discrimination task, since the feeling is not related to degree of stereo-deficiency.

observers can be brought under the control of the same stimulus parameter. The fact that our stereo-deficients report using the same cue as stereonormals, coupled with the fact that the utrocular discriminations of some of the stereo-deficients (like normals) were not better than chance, suggests that the ability to make utrocular discriminations is not related to degree of stereo-deficiency.

In the second of our studies, contrast perception and eye-of-origin discrimination in three stereo-deficient amblyopes was measured. The observers viewed a uniform, 5-deg diameter field presented haploscopically to the two eyes. A test grating was presented to one eye for 167 ms with no change in mean luminance (150 cd/m^2). The test-grating (4 or 8 c/deg) was randomly presented to either eye and was always preceded by a reference pattern presented to the non-amblyopic eye for 167 msec. The reference and test patterns were separated by 500 msec. The observer made a double judgement, one about the eye-of-origin and one about the perceived contrast of the test grating. The eye-of-origin judgement was used to derive a criterion-free measure (d') of the threshold for eye-of-origin discriminations. After both contrast and eye-of-origin judgements were made, feedback was given to the observer regarding the eye stimulated. Feedback about the contrast of the grating was also given, but only on those trials in which the test pattern was delivered to the non-amblyopic eye (i.e., the same eye as the reference). Among the special procedures taken to remove extraneous cues were: (1) the method of constant stimuli was used to present one of 5 contrasts (with 3 dB spacings) to the nonamblyopic eye, and the perceived contrast in the two eyes was equated using a staircase method for the amblyopic eye; (2) the spatial frequency used was randomly varied by up to 5% on each trial to minimize cues due to possible magnification differences between the eyes; (3) the grating was horizontal to minimize cues due to fixation disparity; (4) dichoptic, nonius lines were used to aid alignment of the haploscopic display and the stimuli were presented only when alignment was attained.

The eye-of-origin discrimination results are shown in Fig. 2*. At low contrasts the stereo-deficient observers, like normals, were *unable* to discriminate the eye of origin even though the gratings were quite visible. At higher contrasts only, one stereo-deficient observer, J.M., was able to correctly identify the eye presented with the grating. He reported that at higher contrasts the grating looked differently to his two eyes. At first, the results of J.V. looked similar to those of J.M. When viewing with his fovea, J.V. noticed that on some trials the central part of the grating was "missing" and correctly associated this with the scotoma in his amblyopic eye. To remove the scotoma from the field of view, and therefore to remove it as an extraneous cue, he was instructed to fixate the edge of the stimulus field. In this condition his eye-of-origin judgements were at chance (Fig. 2). (As yet, we have not determined the reason for the difference in the percepts of the grating for J.M.)

Taken together, the results of our two studies, which used very different paradigms, indicate that

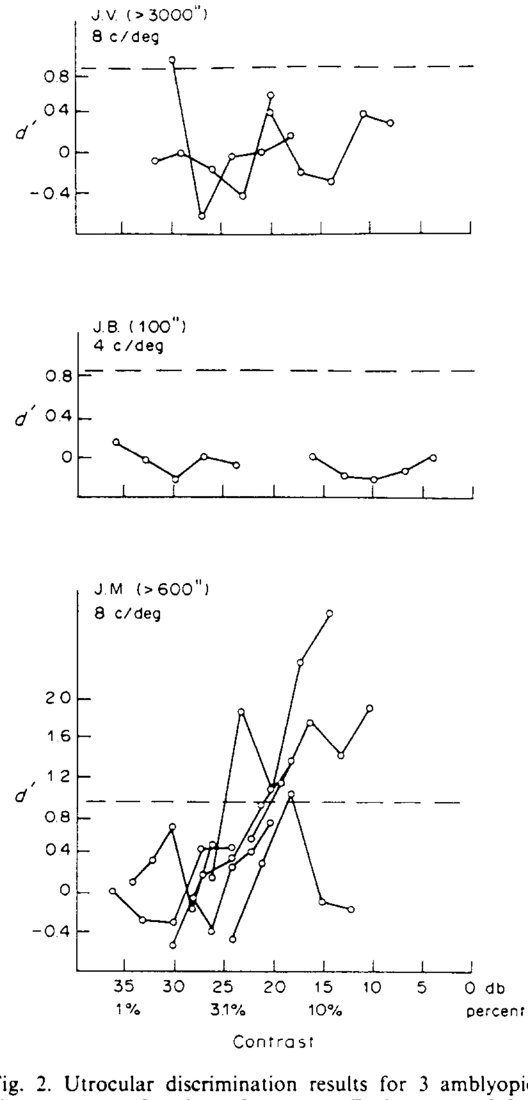

Fig. 2. Utrocular discrimination results for 3 amblyopic observers as a function of contrast. Each group of five connected, data points indicate data collected within one run of approximately 300 trials. Each datum corresponds to the signal detection d' value for matched contrasts. The numbers in parentheses are the observer's stereothresholds. The standard error of d' was about 0.45, so the values of d' above 0.9, indicated by the dashed line, show significant utrocular discrimination [we used spatial frequencies in the range for which it was previously reported (Blake and Cormack, 1979a) that stereonormals could not make utrocular discriminations but stereo-deficients could.] The visual characteristics of the observers were: J.V., esotropic amblyope, 20/20 and 20/80; J.M., anisometropic amblyope, 20/15 and 20/50; J.B., served in both experiments.

*The contrast discrimination results showed that the perceived contrast of the amblyopic eye "caught up" with the perceived contrast of the nonamblyopic eye even under conditions of utrocular confusion.

stereo-deficient observers do not have an advantage over binocularly normal observers when trying to discern which eye is stimulated. If we assume that stereo-deficient humans, like stereo-deficient cats and monkeys (Blake and Hirsch, 1975; Crawford *et al.*, 1983) have a paucity of binocular cortical neurons and a preponderance of monocular neurons, then the results suggest that the eye-of-origin label of these cells is not accessible to consciousness. (We can only speculate on the reason that the results of the two experiments we report here, as well as the preliminary results on stereo-deficients reported by Ono and Barbeito (1985), are different from those of Blake and Cormack (1979a). Our experience is that it is very difficult to equate the percepts (of the grating) in the amblyopic and nonamblyopic eyes. Perhaps this is at the root of the discrepancy in results. Whatever the reason, it cannot be because of the degree of stereo-deficiency of our observers since their stereoacuities ranged from 75″ to greater than 3000″.)

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